

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 2 is an illustration of a processor for applying tone mapping functions to color images.

[0008] Referring to Figure 1, a method of processing a pixel of a digital image includes applying a tone mapping function to a first color channel of the pixel (110), whereby a value of the first color channel is changed by a scale factor; and applying the scale factor to all other color channels of the pixel (112). The first color channel most closely matches relative luminance response of the human visual system.

[0009] The digital image is represented in a linear color space having n -channels that may be designated by A_L and A_k where $k = 1, 2, \dots, n-1$. A_L represents the channel most closely matching a luminance function in the color space, and A_k represents the other $n-1$ channels of the color space. The method of Figure 1 may be represented mathematically as follows:

$$A_L' = \text{TM}(A_L); \text{ and}$$

$$A_k' = SF(A_k) \text{ for } k = 1, 2, \dots, n-1$$

where $TM(\bullet)$ is a tone mapping function, A_L' and A_K' are the modified values of the color channels, and scale factor $SF = A_L'/A_L$. The pixels are processed independently. A scale factor is determined for one color channel of a pixel, and

applied to each other color channel of that pixel. Any tone mapping function may be used.

[0010] When the overall tone properties of the digital image are changed by the tone mapping function, the chromacity of pixels in the image does not change (unlike conventional tone mapping techniques that apply tone-mapping functions to different color channels independently). The method of Figure 1 keeps the chromaticity, or the vector orientation in the A_k color space, or the spectrum shape of each pixel's color approximately the same after the tone mapping; only the vector length in A_k space (or the scale factor of the spectrum) is changed.

[0011] Since almost all images have some degree of noise present, noise-balancing terms may be added to each channel to prevent noise amplification. The noise balancing terms are small positive numbers that are a function of the amount of noise in the image or the white point of the color space used to represent the image. For example, the noise terms may be set to the noise level, twice the noise level, or some other value. As long as the noise balancing terms are reasonably close to the noise level in the image, the method is not sensitive to variations in how the noise level is determined.

[0012] The noise balancing terms may be added as follows. For each pixel, a tone-mapping function is applied to the value of the A_L channel, and the values of the color channels are adjusted as follows:

$$A_L' = TM(A_L); \text{ and}$$

$$A_k' = (A_k + A_{k(\text{noise})}) / (A_L + A_{L(\text{noise})}) \times A_L'.$$

[0013] The addition of the noise balancing terms has very little influence on the chromaticities of high-luminance pixels, but helps reduce the noise amplification problem on low-luminance pixels. The noise balancing terms are also helpful in avoiding division by zero when a zero luminance value is mapped to a non-zero value on the tone curve.

[0014] The method of Figure 1 is applied to an image represented in positive linear color space. Examples of linear positive color space include the

CIE tristimulus XYZ space, RGB space, and human cone sensitivity space. The positive linear color space may include any number of color channels.

[0015] Consider the CIE tristimulus XYZ component representation of a digitized color image. The CIE Y value of an image pixel represents its relative luminance level. For each pixel, a tone mapping function is applied to the Y value and the X and Z values of are adjusted as follows:

$$\begin{aligned} Y' &= TM(Y); \\ X' &= (X + X_{noise}) / (Y + Y_{noise}) \times Y'; \text{ and} \\ Z' &= (Z + Z_{noise}) / (Y + Y_{noise}) \times Y'. \end{aligned}$$

[0016] The terms X_{noise} , Y_{noise} , and Z_{noise} are the noise-balancing terms and they may be small positive values representing the noise levels in each color channel or they may be a triplet of numbers proportional to the white point of the color space used to represent the image.

[0017] In RGB color space, the Green channel is usually the channel that most closely matches the relative luminance response of the human visual system. Therefore, a tone-mapping function is usually applied to the Green channel, and the Red and Blue values are adjusted similarly to keep the color vector orientation constant in the RGB space. Whether the Green channel is tone mapped first depends upon the particular type of color space. In certain instances, either the Red or Blue channel may be tone mapped first instead of the Green channel.

[0018] Reference is made to Figure 2, which shows a processor 210 that is programmed to tone map a color image (IN). The processor 210 applies a tone mapping function to the color channel most closely matching relative luminance response of the human visual system; and applies scale factors to all other color channels. The pixels in the output image (OUT) retain their chromacity. The processor 210 may be used in applications such as digital cameras, scanners, printers, displays, and image processing software applications. Software for the processor 210 is encoded in computer memory 212.

[0019] The present invention is not limited to the embodiments just described and illustrated. Instead, the present invention is construed according to the claims the follow.

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